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A COMPARATIVE STUDY ON THE IMPACT BEHAVIOUR OF THE COATED GLASS PLATES BY FSDT AND HSDT

KOOK CHAN AHN

Professor, Department of Automotive Engineering, Gyeongnam National University of Science and Technology, Jinju, Korea

ABSTRACT

Whitney and Pagano's First-order Shear Deformation Theory (FSDT) and a refined Reddy's Higher-order Shear Deformation Theory (HSDT) are used to interpret the impact behaviour of coated glass plates when they are impacted by an foreign object, The results are to be reviewed in a comparative manner to study the theory and impact behaviour appropriate for future qualitative and quantitative predictions. Consequently, in the macroscopic behaviour aspects (contact force, deflection, kinetic energy), the results of the analysis of FSDT and HSDT for coated glass plates do not differ much. However, there are limits in the microscopic behaviour aspects. That is, both simple FSDT and refined HSDT can be permitted for the macroscopic predictions, but uses of FSDT are limits for microscopic behaviour predictions.

KEYWORDS: Monolithic Glass (MG), Coated Glass (CG), Impact Behaviour & Higher-Order Shear Deformation Theory (HSDT)

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Original Article

INTRODUCTION

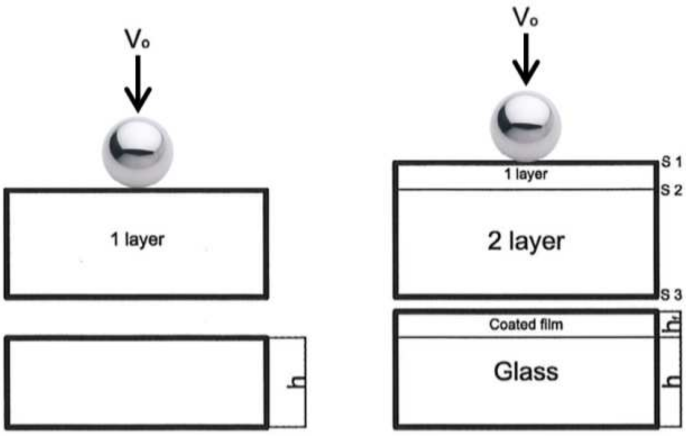
Accurately predicting impact behaviour on the foreign object impact of coated glass plates is very difficult to interpret because of the momentary impact time and the complex indentation. Although a number of experimental and analytical studies have been conducted on composite materials or laminated glasses, analytical studies on coated glass plates are minimal.

In general, Hertz's contact law [1] is used to describe most common contact phenomena, but this is not valid because of its complexity in characterizing the contact force and indentation relation when there is a thin film junction.

Kurapati [2] demonstrated its validity by proposing a generalized power law on film thickness and modulus in coating glass plates. Recently, Kang [3] demonstrated their validity by studying the impact behaviour of coated glass plates in conjunction with the FSDT and a generalized power law.

In this study, a new sophisticated analytical technique is proposed that is linked to the HSDT with a generalized power law to compare the impact behaviour of coated glass plates and reviews the usefulness of qualitative and quantitative prediction based on the FSDT [4] and HSDT [5] for the monolithic glass plate (MG) and coated glass plates (CG).

THEORETICAL BACKGROUND



(a) (b)

Figure 1: Schematic Diagram of (a) Monolithic Glass Plate (MG) and(b) Coating Glass Plate (CG) [3]

Figure 1 is a geometric representation of the MG and CG and assumes a ball falling to the initial impact velocity V0, which is sufficient to prevent the glass layer from being destroyed.

Whitney and Pagano's FSDT [4] and Reddy's HSDT [5] are expressed as follows:

[FSDT]

$u(x, y, z, t) = u_0(x, y, t) + z\varphi_x(x, y, t)$

$v(x, y, z, t) = v_0(x, y, t) + z\varphi_y(x, y, t)$ (1)

$w(x, y, z, t) = w_0(x, y, t)$

[HSDT]

$u(x, y, z, t) = u_0(x, y, t) + z[\varphi_x - (4z^2/3h^2)(\varphi_x + w_{,x})]$

$v(x, y, z, t) = v_0(x, y, t) + z[\varphi_y - (4z^2/3h^2)(\varphi_y + w_{,y})]$ (2)

$w(x, y, z, t) = w_0(x, y, t)$

where (u_0, v_0, w_0, φ_x, φ_y) are unknown functions to be determined.

A generalized power law [2] of contact force and indentation relation is given as follows:

$F=CE_s\delta^p$(3)

The overall simulation process and the material properties of target and impactor for this simulation are shown in Ref. [3].

RESULTS AND DISCUSSIONS

Table 1 is a comparison of present results and theoretical models (wave propagation model and energy balance model) [6]. To demonstrate two simulations based on FSDT and HSDT, maximum contact forces and contact durations are compared with two theoretical models. In terms of maximum contact forces and contact durations, there is a very good match between the FSDT and HSDT in present results and two theoretical models, but the results of present results and two

theoretical models in of maximum contact forces show a slight discrepancy, but the overall trend is well matched. Comparing the two analysis results by the FSDT and HSDT shows that the maximum contact forces by FSDT are slightly greater than those by HSDT, but the contact durations by two theories are very well matched. Figure 2 shows the results (the histories of contact forces, plate deflection, ball displacement and indentation for MG with glass, and CG with coating film and a glass of the same thickness) obtained by FSDT & HSDT. From Figure 2, the results of the two theories on contact force and contact duration in case of CG are almost identical, but in terms of plate deflection, the results of CG are slightly greater. Comparing these computational results of the two theories, the same trend is shown, and the error is not so great, so FSDT is easier to use if you want to know the contact force and deflection. Relationship of contact force-indentation and deflection-indentation by FSDT & HSDT can be depicted by the curve shown in Figure 3. The results of the two theories show a similar tendency, but the case of CG over MS indicates a much larger amount of deflection and indentation. We can see that this is the strength effect of CG film.

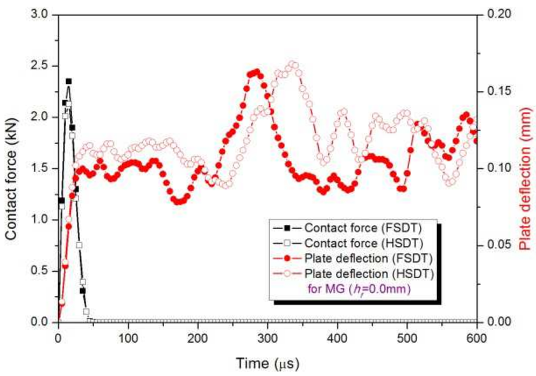
Table 1: Comparison of Present Result and Wave Propagation Model and Energy Balance Model: (a) Max. Contact Force (b) Contact Duration

(a)

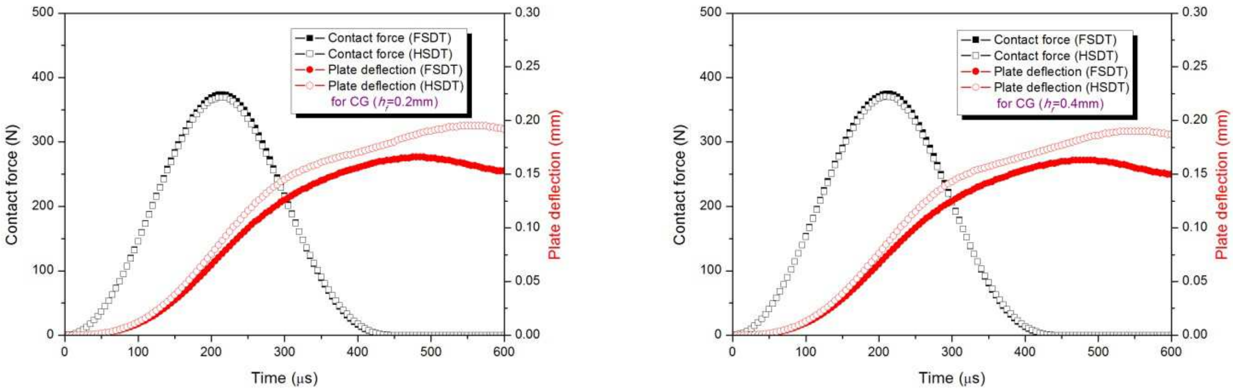
Max. Contact Force (N)					
Present Results		Wave Propagation Model (WPM)		Energy Balance Model (EBM)	
FSDT	HSDT	FSDT	HSDT	FSDT	HSDT
2,350	2,130	2,320	2,180	5,200	5,200
374	369	294	292	320	320
375	371	304	301	328	328
377	373	310	313	335	335

(b)

PET Thickness (mm)		Contact Duration (μs)					
		Present Results		Wave Propagation Model (WPM)		Energy Balance Model (EBM)	
		FSDT	HSDT	FSDT	HSDT	FSDT	HSDT
MG	0.0	50.0	50.0	28.0	28.0	28.8	28.8
CG	0.2	450.0	450.0	469.0	469.0	469.0	469.0
	0.4	445.0	445.0	458.0	458.0	458.0	458.0
	0.6	440.0	440.0	448.0	448.0	448.0	448.0

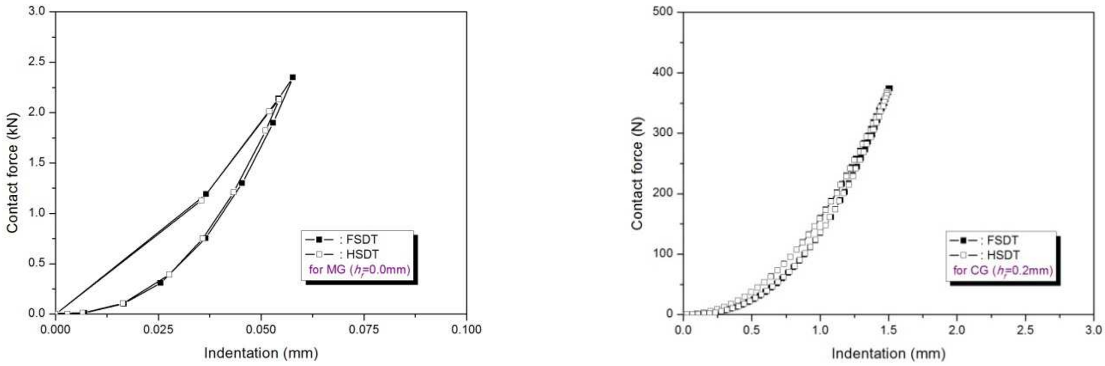


(a)



(b)

Figure 2: Histories of Contact Force and Deflection of (a) MG and (b) CG



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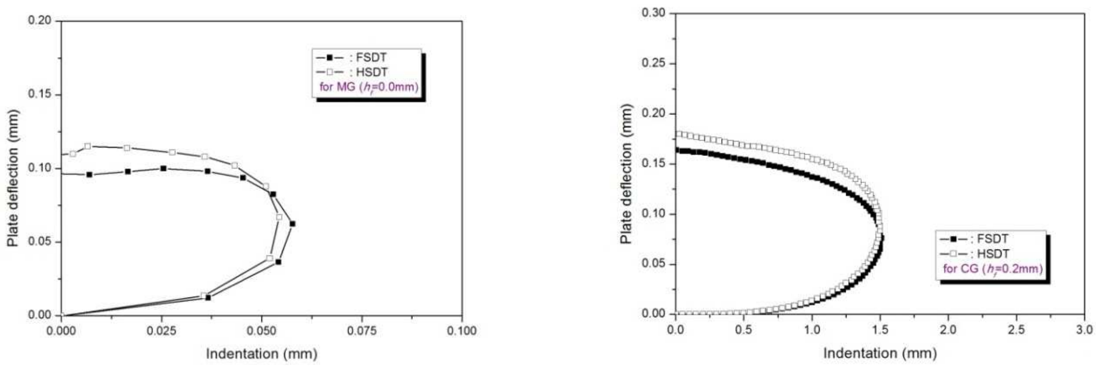
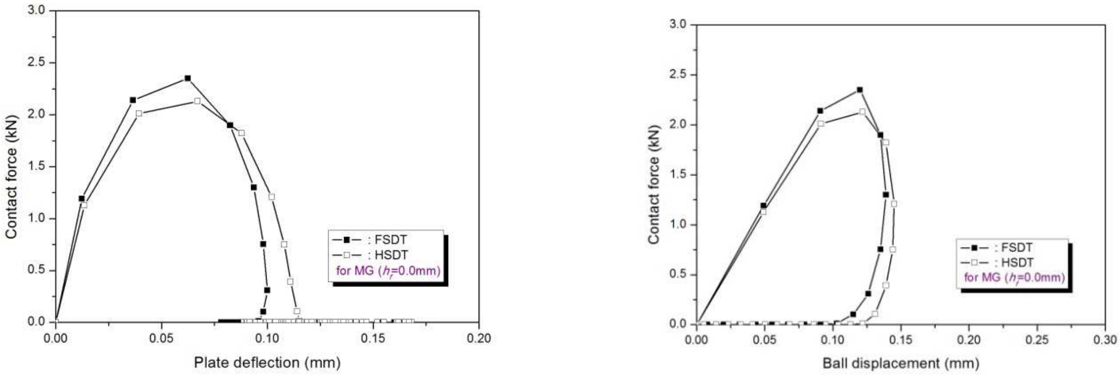


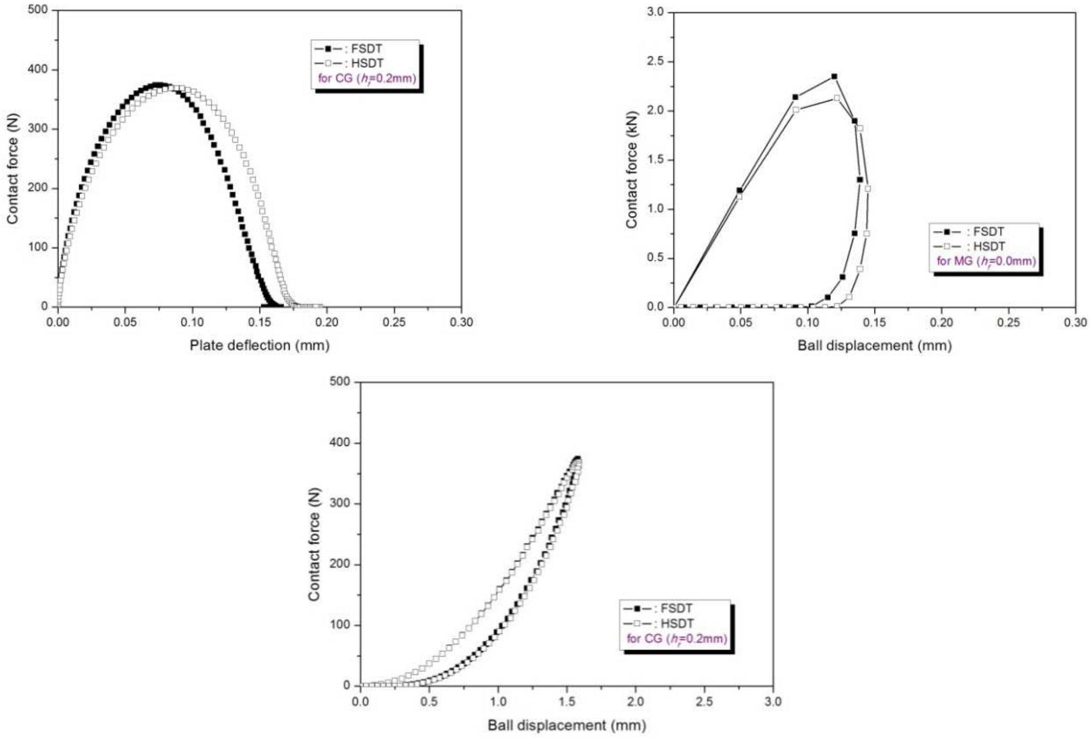
(b)

Figure 3: Relation of (a) Contact Force-Indentation and (b) Deflection-Indentation of MG and CG

Figure 4 depicts contact force-plate deflection and contact force-ball displacement curves of MG and CG by FSDT & HSDT. Comparing the two analysis results in MG shows a difference of about 10% in maximum contact force, maximum deflection and ball displacement, CG shows the same maximum contact force, but maximum deflection and maximum displacement of 10 per cent.



(a)



(b)

Figure 4: Relationship of Contact Force-Plate Deflection and Contact Force-Ball Displacement of (a) MG and (b) CG

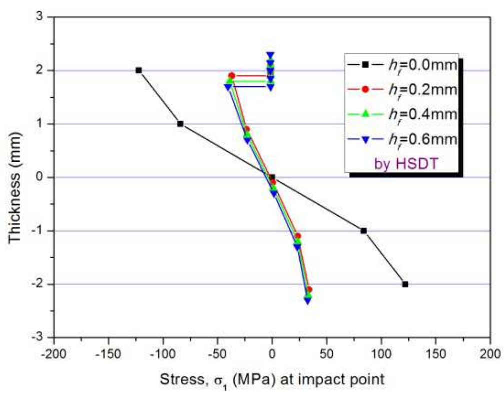


Figure 5: Variations of Stress through the Layer of MG and CG at Impact Point

Figure 5 shows the results of impact behaviour with MG and changes in the film thickness of CG by HSDT. Although the stress magnitudes between MG and CG show a large difference, the analysis results of film thickness changes of the CGs are not likely to show much variation. All stress components by FSDT vary linearly through the thickness [3], whereas the variations of stress by HSDT show the variation of nonlinearity. And from the analysis results of HSDT shown in Figure 5 show the discontinuance due to a significant difference of material properties between the film and glass of CG. In case of MG without the film, the damage is rapidly carried out from the impacted surface to the opposite surface, but in case of film CG with film, the film absorbs the impact and greatly prevents the damage. In addition, to protect the glass from foreign object impact, the presence of the film is very important rather than the thickness of the film, which is very similar to the role of intermediate PVB film of the laminated glass [7-10].

CONCLUSIONS

In order to better predict the impact behaviour of coated glass plates subject to external impacts, a refined finite element approach based on a Reddy's Higher-order Shear Deformation Theory (HSDT) associated with a generalized power as a contact law is proposed, and a comparative review of simulation results by the FSDT and theoretical models (wave propagation model and energy balance model) resulted in the following conclusions:

- A reliability analysis could be made by presenting a new simulation technology linking the appropriate contact law with the first-order and the higher-order shear deformation theory to predict impact behaviour of coated glass plates.
- In the macroscopic behaviour aspects (a contact force, deflection, kinetic energy), the results of the analysis of FSDT and HSDT of coated glass plate do not differ much. However, there are limits in the microscopic behaviour aspects. That is, both simple FSDT and refined HSDT can be permitted for the macroscopic predictions, but uses of FSDT are limits for microscopic behaviour predictions (stress and strain etc. of multi-layer structures).
- To protect the glass from foreign object impact, the presence of the film is very important rather than the thickness of the film, which is very similar to the role of intermediate PVB film for protection of interior glass of the laminated glass.

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